Single transverse-spin asymmetry measurement in neutral pion and charged hadron production at PHENIX

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for the PHENIX collaboration

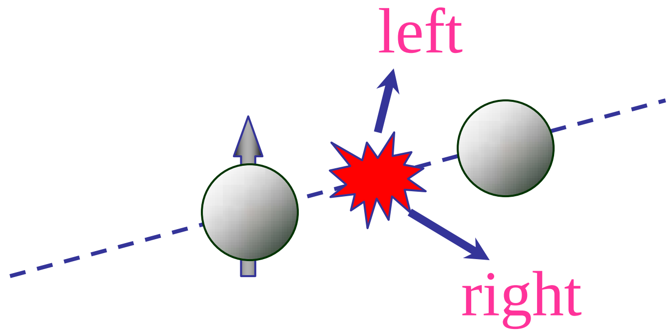
Outline

- Introduction
  - single transverse-spin asymmetry (A_N) measurements
  - possible effects
- Measurement at PHENIX mid-rapidity
  - π^0 and charged hadrons
  - asymmetry calculation and systematic error
- Results and summary
  - cross section and A_N

Single transverse-spin asymmetry (A_N)

- Left-right asymmetry

$$A_N = \frac{d\sigma_{Left} - d\sigma_{Right}}{d\sigma_{Left} + d\sigma_{Right}}$$

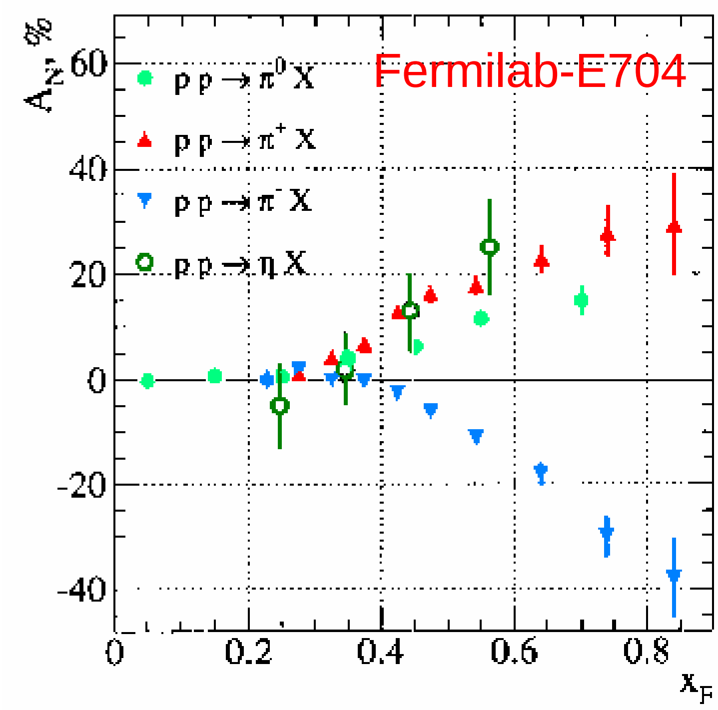


- Forward-rapidity
  - Fermilab-E704
    - fixed-target experiment at $\sqrt{s}$ = 19.4 GeV
  - RHIC-STAR
    - $\sqrt{s}$ = 200 GeV
    - large asymmetry at $x_F > 0.3$
  - and more fixed-target data at lower energies

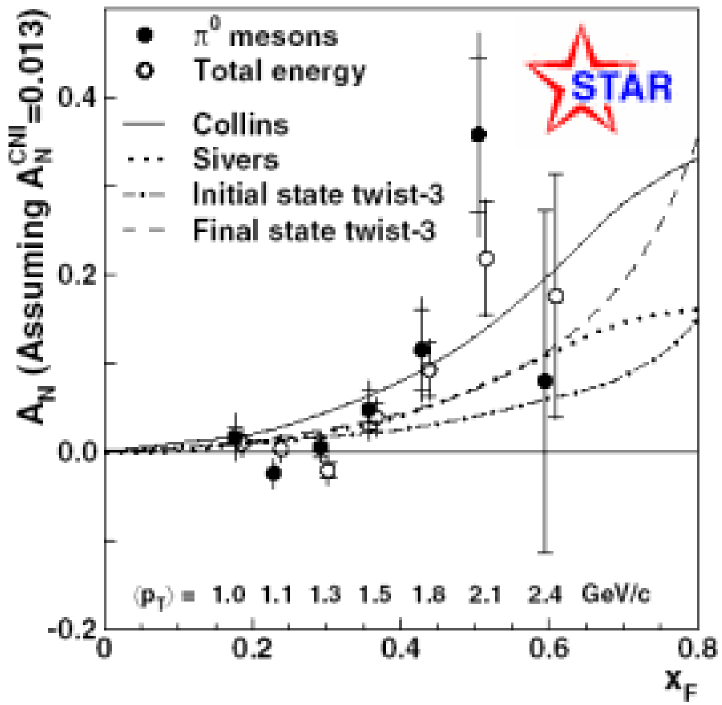
Single transverse-spin asymmetry (A_N)

- Forward-rapidity
  - ~ 20% asymmetry
  - many QCD-based theories developed

$\sqrt{s}$ = 19.4 GeV



$\sqrt{s}$ = 200 GeV



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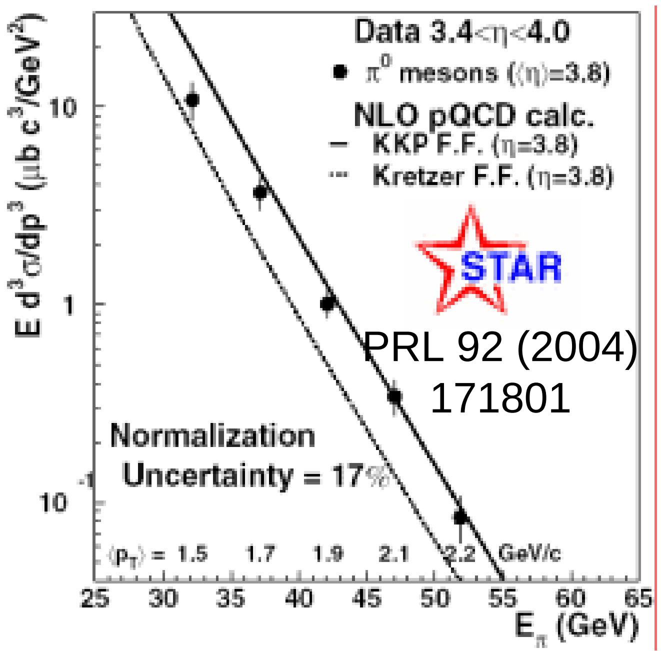
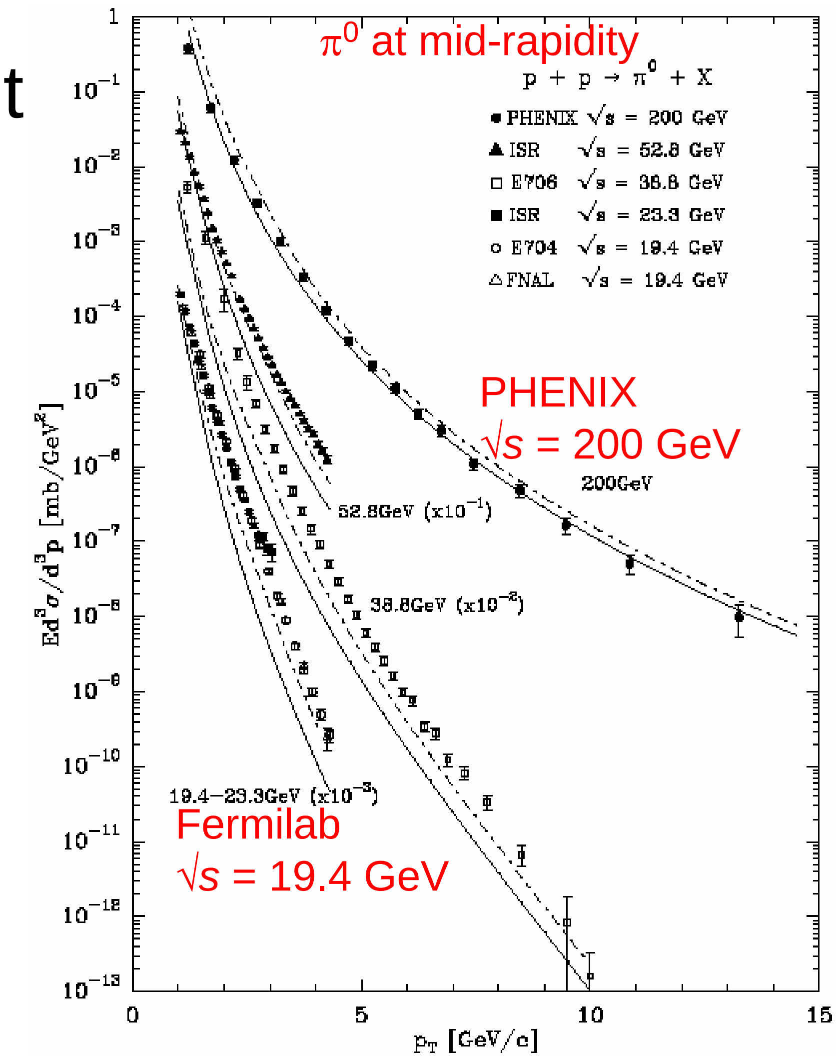
Disentangle possible effects

- Sivers effect
    - left-right asymmetry in transverse momentum distribution of partons (“k_T”) inside the transversely polarized nucleon
- Transversity & Collins effect
    - transversity
        - transverse polarization of partons inside the transversely polarized nucleon
            - last unmeasured leading-twist distribution
    - Collins fragmentation function
        - left-right asymmetry (analyzing power) in the fragmentation process of transversely polarized final partons
- Higher-twist effect

Disentangle possible effects

- Soft physics at fixed-target energy ?
  - important to show cross section measurement



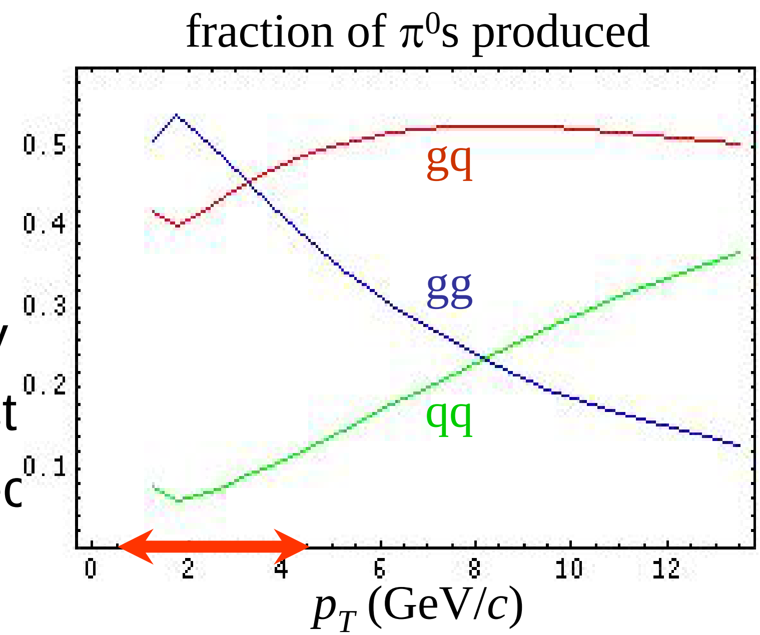


Bourrely and Soffer
hep-ph/0311110

- Advantage of RHIC

Mid-rapidity at PHENIX

- Different kinematic region
  - forward-rapidity at STAR ($x_F > 0.3$)
    - quark-gluon reaction dominant
    - large contribution from x ~ 0.6 quark polarization/transversity
  - mid-rapidity at PHENIX ($x_F \sim 0$)
    - contribution from both gluon-gluon and quark-gluon reactions
    - x = 0.03 – 0.1
    - small quark polarization/transversity
    - no gluon transversity in leading twist
    - negligible transversity & Collins effect contribution



Polarized-proton runs at RHIC

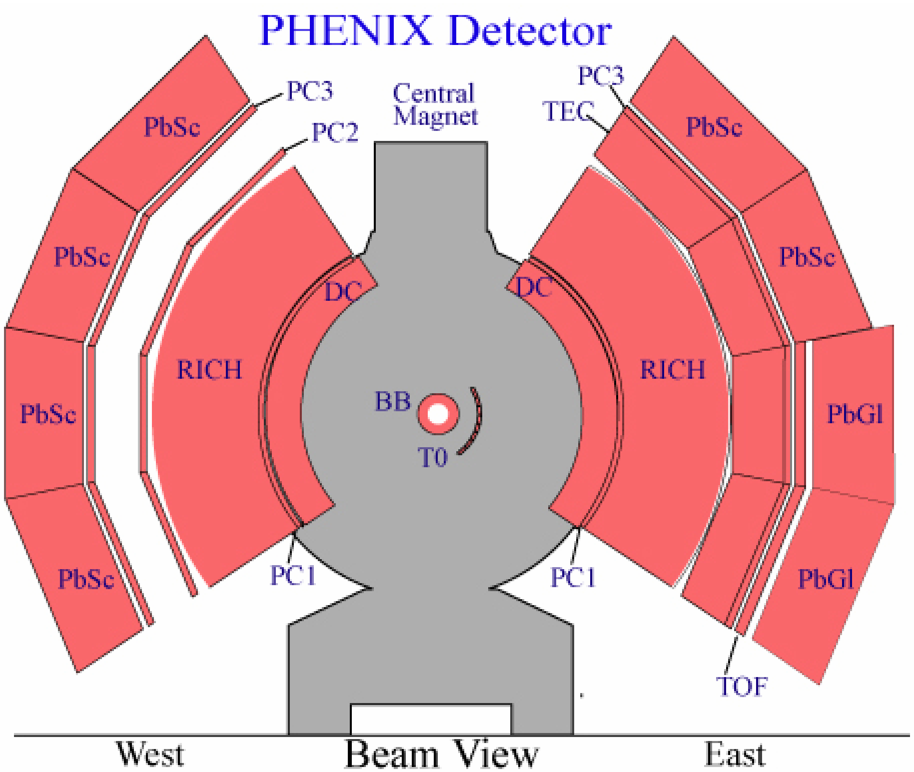
- 2001 – 2002
  – transverse polarization ~ 15%
  – integrated luminosity 0.15 pb^{-1}

← this presentation

- 2003
  – longitudinal polarization ~ 27%
  – integrated luminosity 0.35 pb^{-1}
- 2004
  – 5 weeks machine development
  – longitudinal polarization ~ 40%
  – integrated luminosity ~ 0.1 pb^{-1}

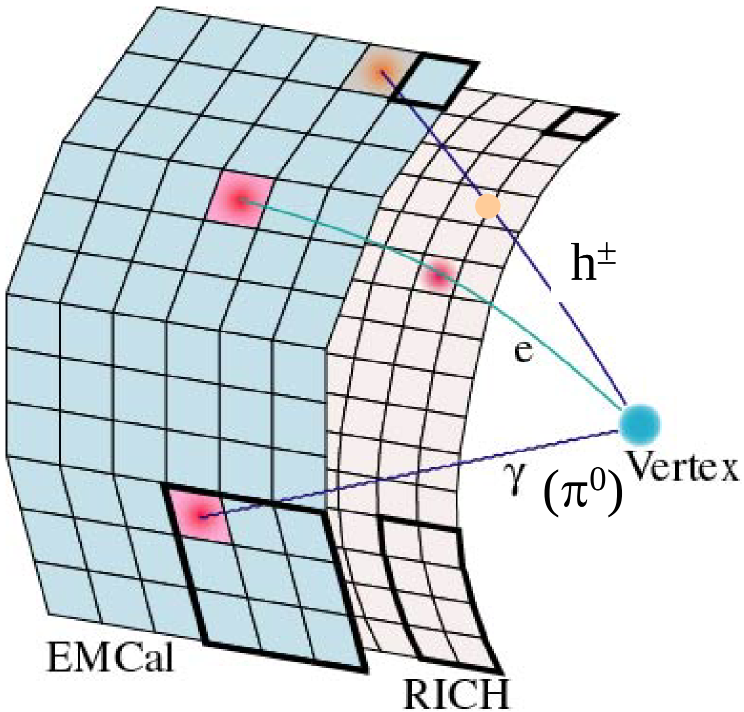
PHENIX detector

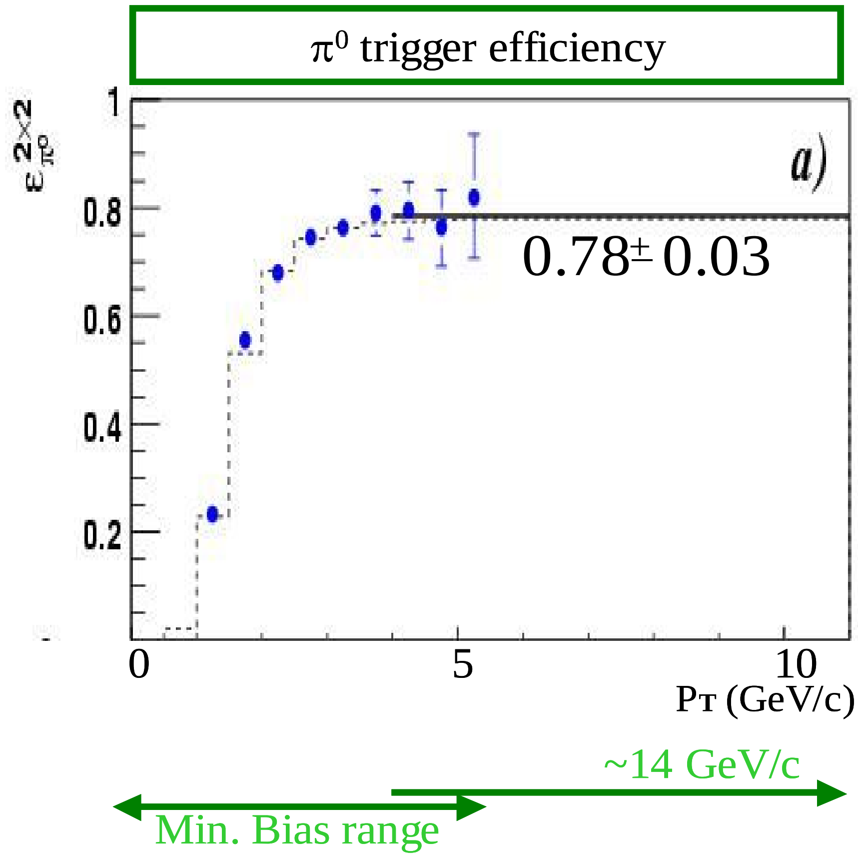
- Central arms
  - $|\eta| < 0.35$, $\Delta\varphi = 90° \times 2$
  - π^0 measurement
    - EMCal: EM calorimeter
      - PbSc: lead-scintillator
      - PbGl: lead glass
  - charged hadron measurement
    - DC: drift chamber
    - PC: pad chamber
    - RICH: ring-image Cherenkov counter
    - EMCal



Trigger system

- Minimum-bias
  - BBC (beam-beam countrer)
- High-p_T trigger
  - EMCal-RICH trigger
  - 0.8 GeV EMCal threshold





Asymmetry calculation

- Square-root formula

$$A_N = \frac{1}{P} \cdot \frac{\sqrt{N_{\uparrow L} \cdot N_{\downarrow R}} - \sqrt{N_{\uparrow R} \cdot N_{\downarrow L}}}{\sqrt{N_{\uparrow L} \cdot N_{\downarrow R}} + \sqrt{N_{\uparrow R} \cdot N_{\downarrow L}}}$$

  – detector / luminosity asymmetry cancelled in O^3(asym) order
- Luminosity formula

$$A_N = \frac{1}{P} \cdot \frac{N_{\uparrow \mathrm{L/R}} - R \cdot N_{\downarrow \mathrm{L/R}}}{N_{\uparrow \mathrm{L/R}} + R \cdot N_{\downarrow \mathrm{L/R}}} \qquad R = \frac{L_\uparrow}{L_\downarrow}$$

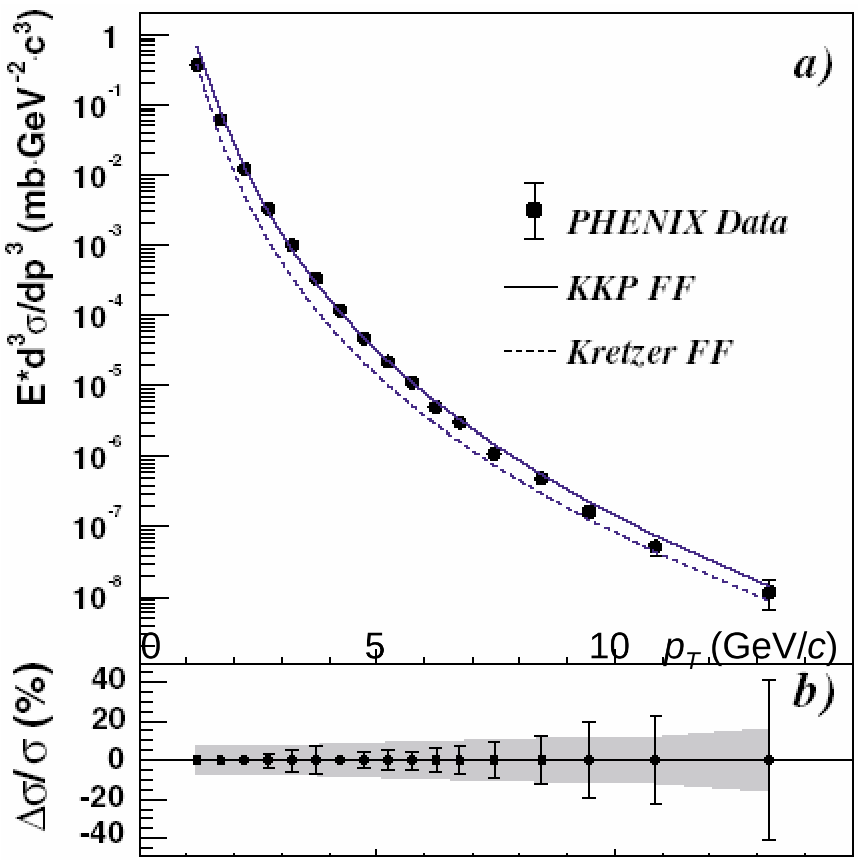
  – for left and right detectors independently
  – R: relative luminosity
    - measured by BBC and ZDC (Zero-Degree Calorimeter)
  – P: RHIC polarization
    - next two talks (O. Jinnouchi and H. Okada)

Systematic error evaluation

- comparison of independent measurement for two polarized beams
  - both beams (“blue” and “yellow”) polarized
- comparison of independent measurement for left and right detectors
- comparison of minimum-bias and high-p_T triggered data samples
- store-by-store consistency of asymmetry values
- “bunch shuffling”
  - randomly reassign the polarization direction for each bunch crossing
  - recalculate the asymmetry
  - repeat many times to produce a shuffled asymmetry distribution centered around zero
  - compare width of “shuffled” distribution to statistical error on the physics asymmetry

Results

- Neutral pion



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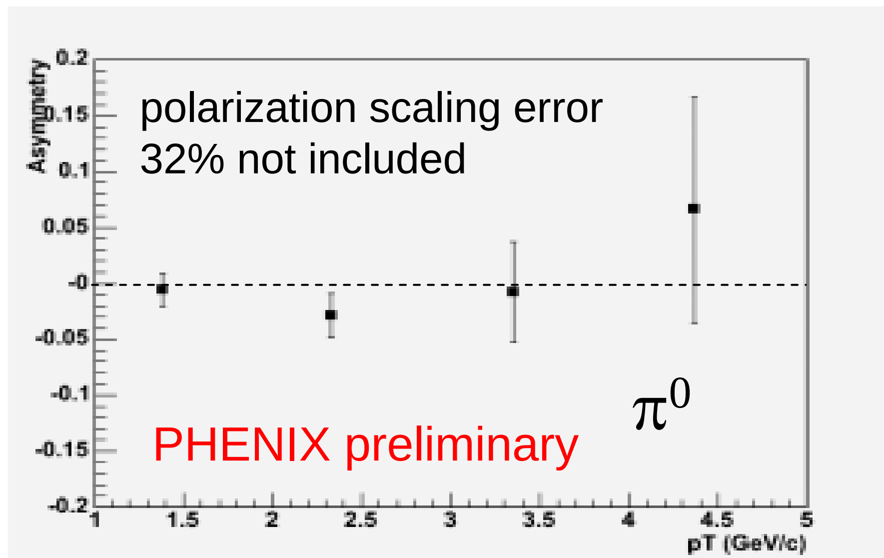
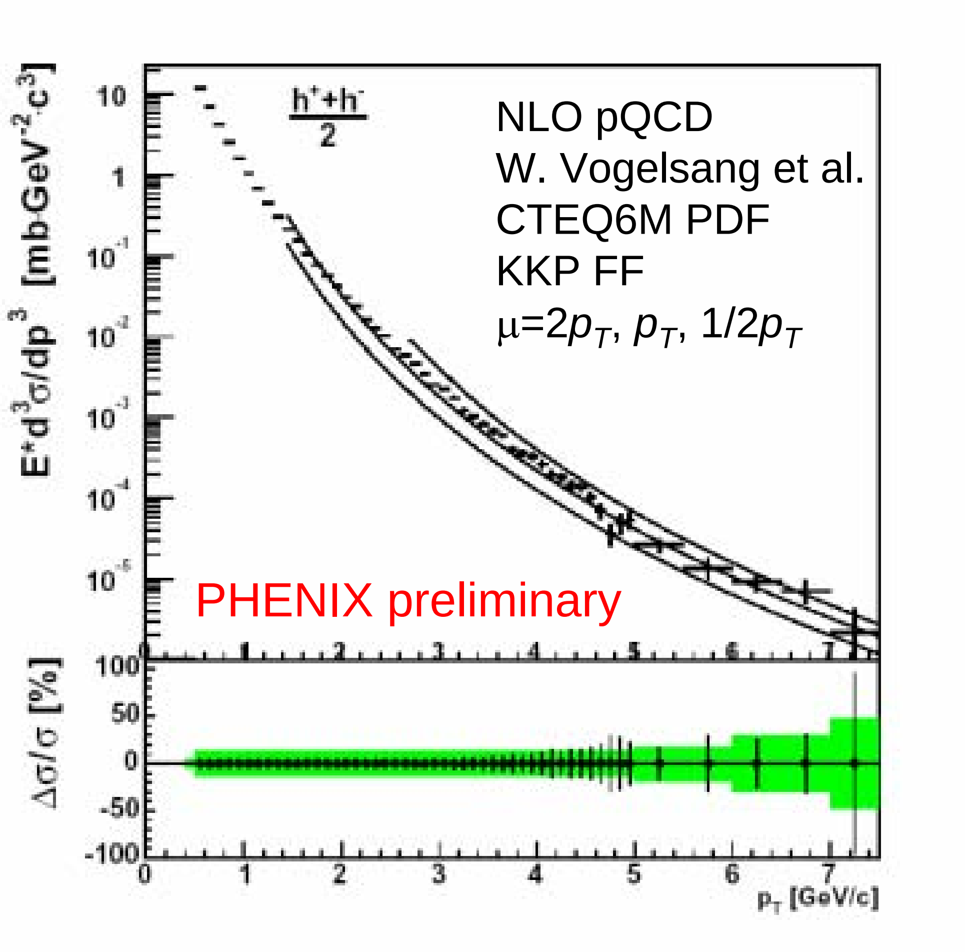
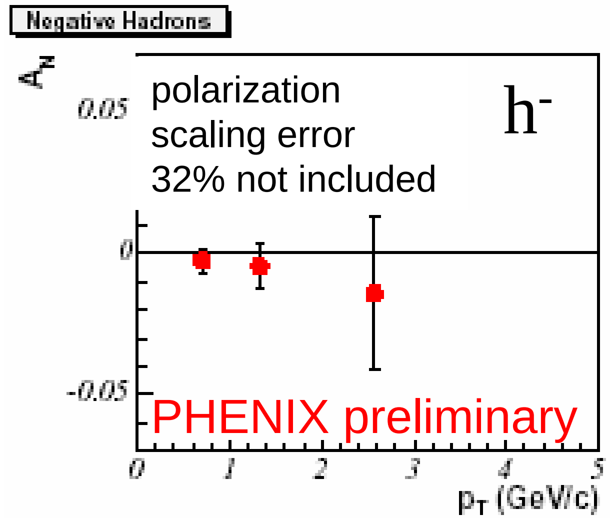
- data covers over 8 orders of magnitude
- NLO pQCD calculation is consistent with our data
- no significant soft physics component

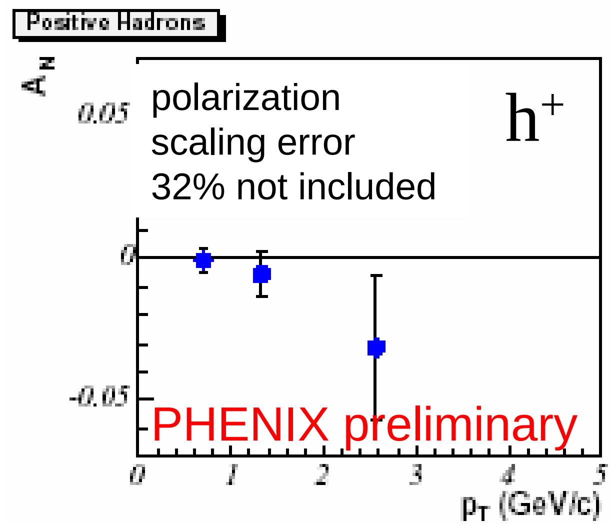


Results

- Charged hadrons

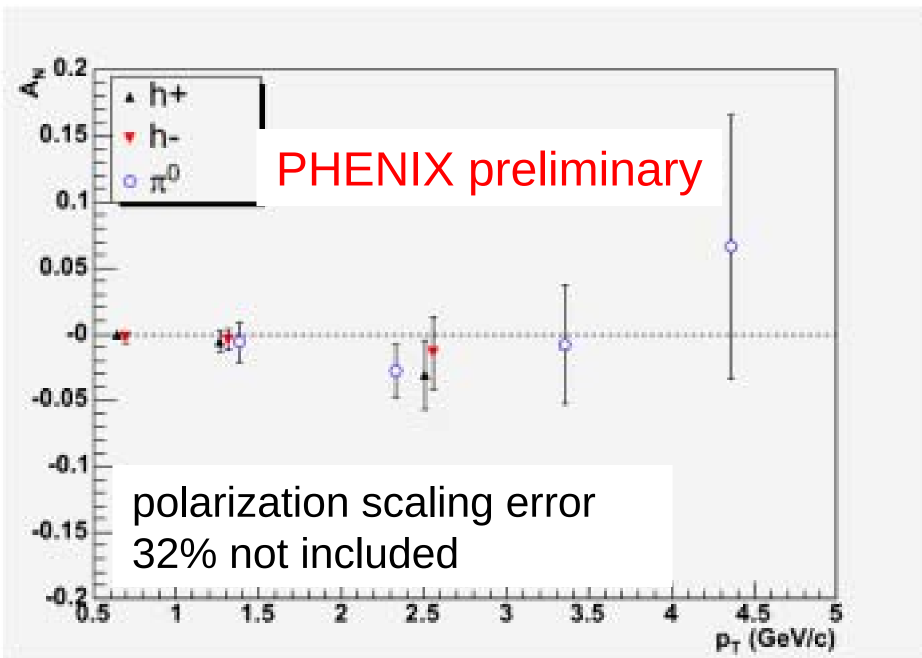


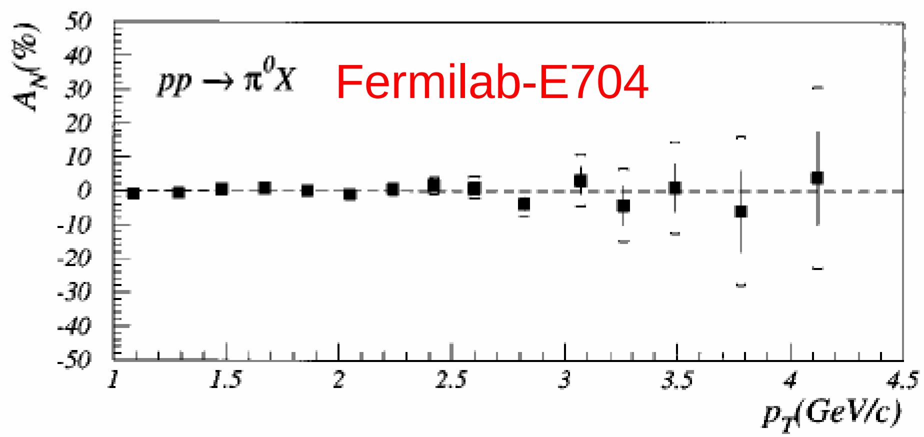




Results

- A_N for both π^0 and charged hadrons consistent with zero at mid-rapidity
- 5-10 times smaller asymmetry than STAR forward-rapidity data (~ 20%)
- comparable data with Fermilab-E704 for π^0 and charged hadrons





Phys.Rev.D53 (1996) 4747

Summary

- cross section and A_N of π^0 and charged hadrons measured at mid-rapidity, $\sqrt{s}$ = 200 GeV
- A_N of both π^0 and charged hadrons consistent with zero
- 5-10 times smaller asymmetry than STAR forward-rapidity data (~ 20%)
- expected to be compared with QCD-based theory calculations
- expected to be used to disentangle many possible effects by combining other data

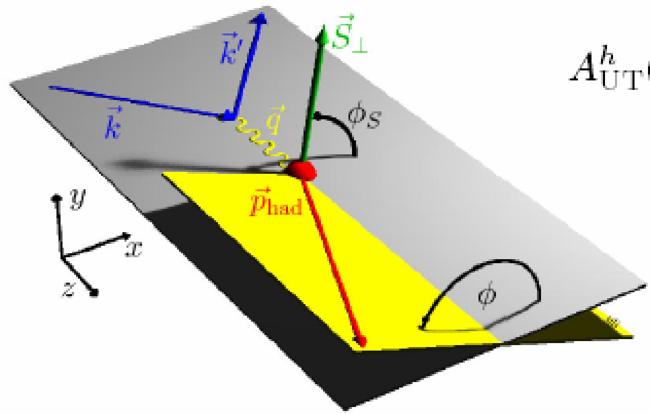
Backup slides

Summary

- cross section and A_N of π^0 and charged hadrons measured at mid-rapidity, $\sqrt{s}$ = 200 GeV
- A_N of both π^0 and charged hadrons consistent with zero
- 5-10 times smaller asymmetry than STAR forward-rapidity data (~ 20%)
- expected to be compared with pQCD calculations
- expected to be used to disentangle many effects by combining other data
  - other information source
    - polarized semi-inclusive DIS at Hermes, SMC, Compass
    - fragmentation function at Belle

HERMES

- Polarized semi-inclusive DIS



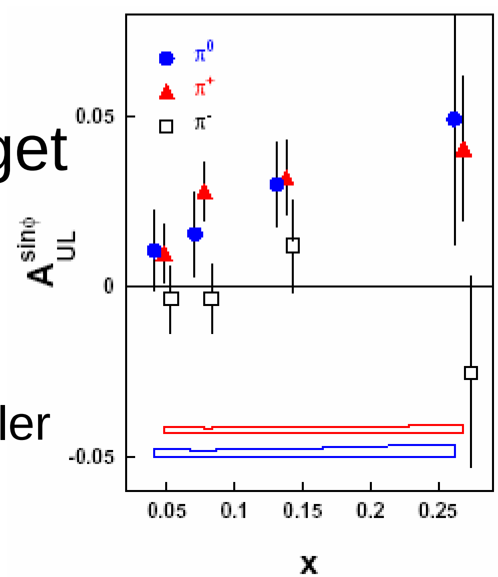
$$
\begin{aligned}
A^h_{\rm UT}(\phi,\phi_S) &= \frac{1}{|P_T|}\frac{N_h^\uparrow(\phi,\phi_S)-N_h^\downarrow(\phi,\phi_S)}{N_h^\uparrow(\phi,\phi_S)+N_h^\downarrow(\phi,\phi_S)} \\
&= A^{\rm Collins}_{\rm UT}\,\sin(\phi+\phi_S) \\
&+ A^{\rm Sivers}_{\rm UT}\,\sin(\phi-\phi_S)
\end{aligned}
$$

→ fit amplitudes ***simultaneously***
(prevents mixing of effects by acceptance)

longitudinal polarized target

A_{UL}

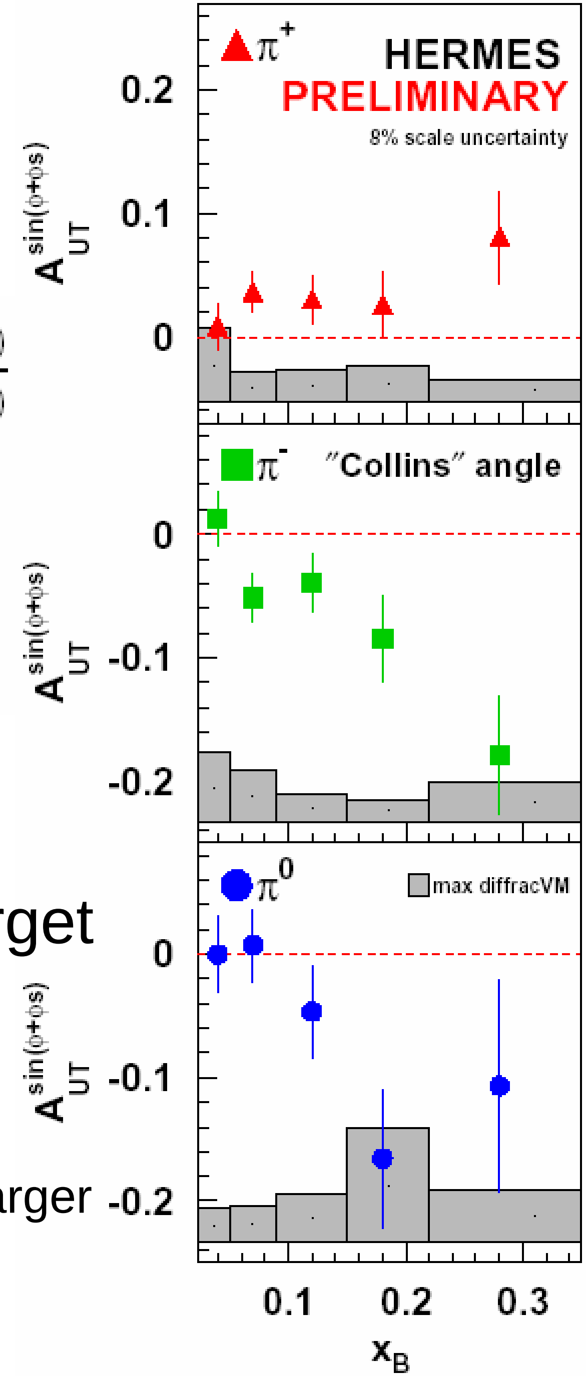
$A^{\pi+} \sim A^{\pi 0} > 0$
$A^{\pi-} < 0$ and smaller



transverse polarized target

$A_{UT}^{Collins}$

$A^{\pi+} > 0$
$A^{\pi 0} \sim A^{\pi-} < 0$ and larger

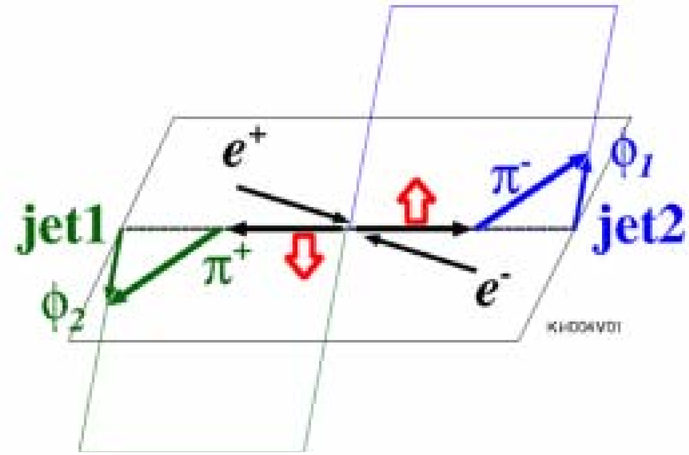


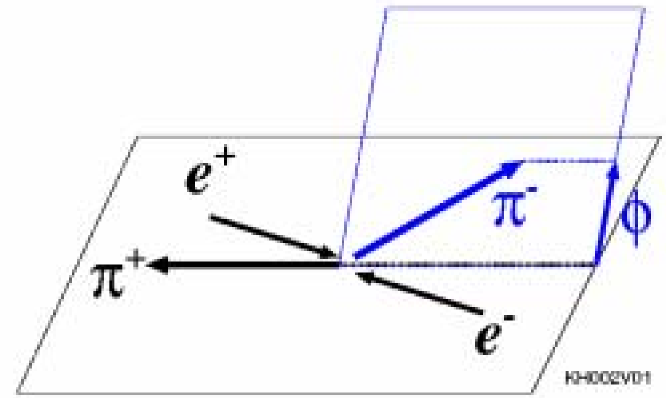
Fragmentation function at BELLE

- Collins fragmentation function
  - $e^+e^- \rightarrow \pi^+_{jet1}\pi^-_{jet2}X$
  - reaction plane defined with beam (z-axis) and jet axis
  - product (π) plane defined with π and jet axis
  - ϕ: angle between the planes

    $A \propto H_1^\perp(z_1)H_1^\perp(z_2)\cos(\phi_1+\phi_2)$
  - can analyze with/without using jet axis

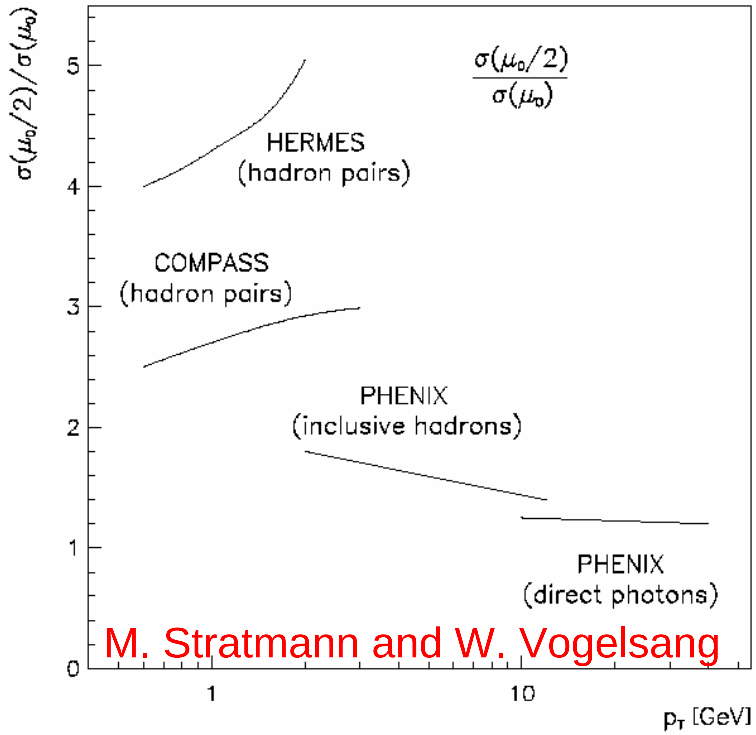
    $A \propto H_1^\perp(z_1)H_1^\perp(z_2)\cos(2\phi)$





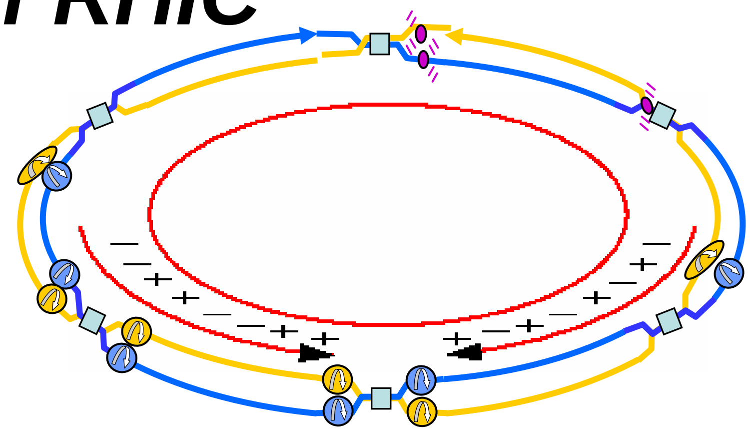
Advantage of RHIC

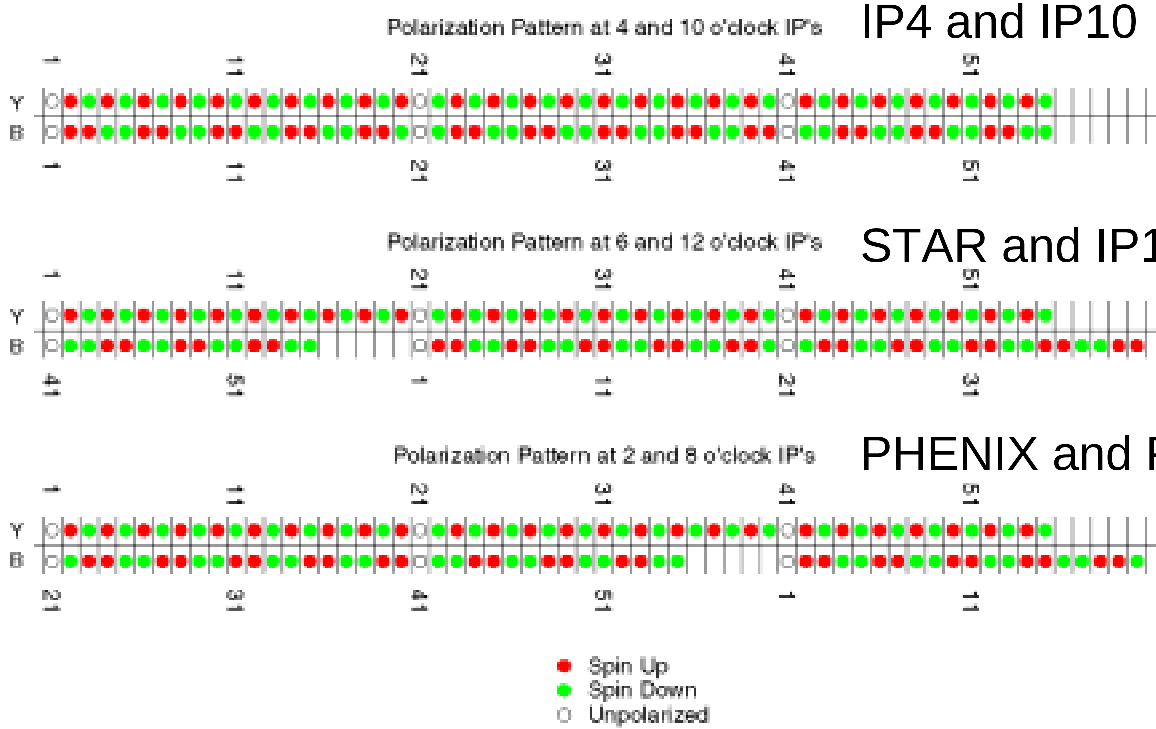
- High $\sqrt{s}$ and high Q^2
  - $\sqrt{s}$ = 200 GeV and 500 GeV in the future
  - perturbative QCD applicable
    - scale dependence of the NLO pQCD calculation in the cross section measurement
    - scale dependence is expected to largely cancel in the asymmetry measurement



Advantage of RHIC

- Cancellation of systematic uncertainty
  - flexible combination of spin direction every crossing





IP4 and IP10

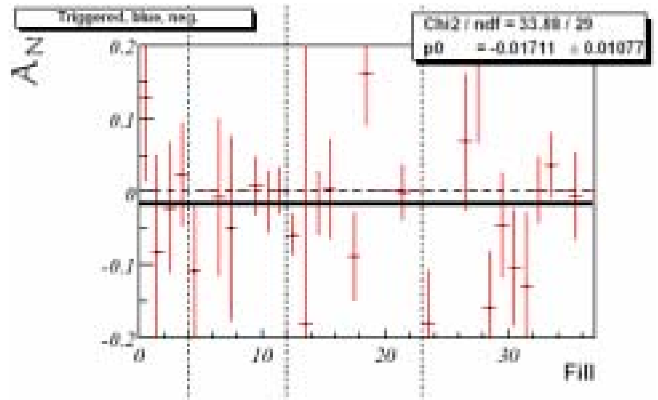
STAR and IP12

PHENIX and PP2PP

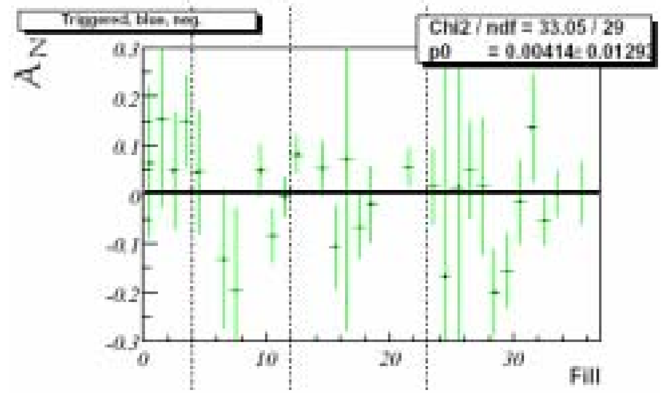
Store-by-store consistency

- Charged hadrons
  - fitting

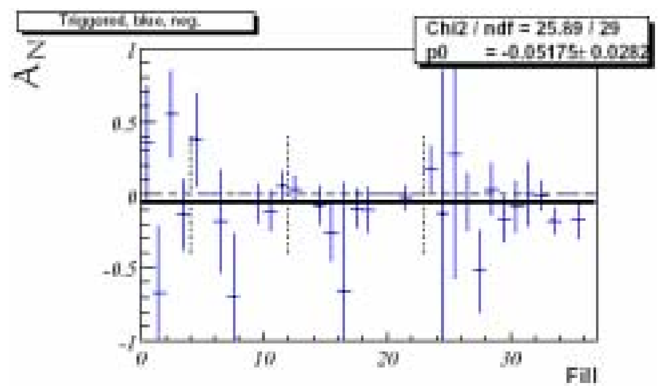
$0.5\ \mathrm{GeV}/c < p_T < 1\ \mathrm{GeV}/c$



$1\ \mathrm{GeV}/c < p_T < 2\ \mathrm{GeV}/c$

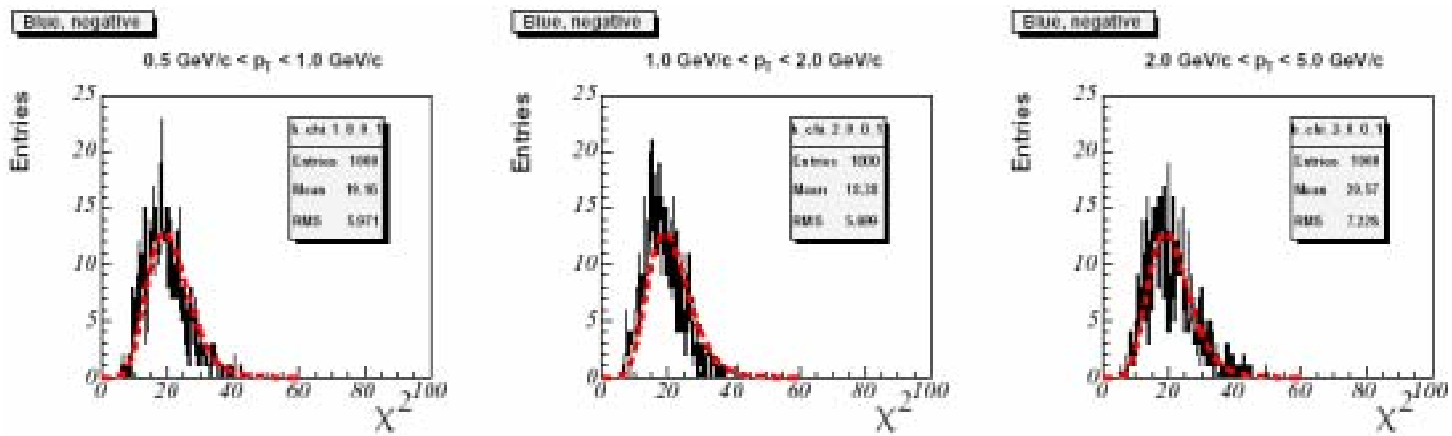


$2\ \mathrm{GeV}/c < p_T < 5\ \mathrm{GeV}/c$



Bunch shuffling

- Charged hadrons
  - compare χ^2 distribution from shuffling



  - compare width of shuffled distribution